Indian J. Phys. **51A**, 429–434 (1977)

Effect of tempering temperatures on the mechanical properties of Cu-Al alloy

S. A. Salam, H. R. Moustafa, M. M. Ezzo, and S. A. Mohamed

Physics Department, Islamic Girls' College, Al-Azhar University, Cairo, Egypt

(*Received* 7 *September* 1976)

Measurements on the mechanical properties (hardness, tensile strength and impact toughness) of a Cu—Al 11.6 wt.% alloy have been carried out at different tempering temperatures (400-700°C). Maximum hardness, maximum tensile strength and minimum impact toughness were obtained at 400°C, while minimum values were found at 500°C. Micro-structural investigations confirm these results. It was found that the $(\alpha+\gamma_2)$ hard eutectoid phase was predominant at 400°C.

Introduction

Lot of work was carried out on the structure[1–5] of Cu—Al alloys. Also the structure and properties of martensite in aluminium bronze have been studied on isothermal[6–9] and continuous cooling[10–12]. But only few investigations were carried out on the tempering characteristics [13–17] and on the mechanical properties[18–20] of these alloys.

The present work investigates the effect of tempering on the mechanical properties and the microstructure of aluminium bronze alloys.

Heat treatment

Specimens, from the prepared alloy, were homogenised by heating at 850°C in an electric annealing furnace for 24 hours[21], furnace cooled till 400°C and then air cooled to room temperature.

The homogenised specimens were reheated at 850°C P_{-1}
quenched directly in water for martensitic transformation.

Tempering has been carried out by heating four different groups of martensites for four hours at 400, 500, 600 and 700°C respectively, and then air cooled to room temperature.

Measurements of Mechanical Properties and Microstructural investigations

Hardness measurements have been carried out using Brinell hardness tester using a load of 62.5 kg and a ball diamter of 2.5 mm.

Tensile strength was measured using the universal testing machine ZD20.

Impact toughness measurements have been carried out using the pendulum type impact testing machine type (BSW 30/15) of Mohr and Fedrho Manufacture of W. Germany.

Table 1. Results of the mechanical properties

Tempering temperature (°C)	Hardness (B.H.N)	Tensile strength, σ (kg/mm^2)	Impact toughness, α (kg/cm^2
400	241	69	1
500	189	50	15
600	229	62	11
700	229	62	11
Homogenised (at 850°C)	199		

Microstructural changes associated with tempering were examined by an optical microscope type MNM. 8M made in USSR. The specimens were etched with a ferric chloride solution containing 5 gms $FeCl_3$, 30 c.c. HCl and 100 c.c. water.

Results and Discussion

The results obtained for the mechanical properties of the binary Cu-Al 11.6% alloy as a function of tempering temperatures are given in Table 1 and represented graphically in Figures. 1 and 2.

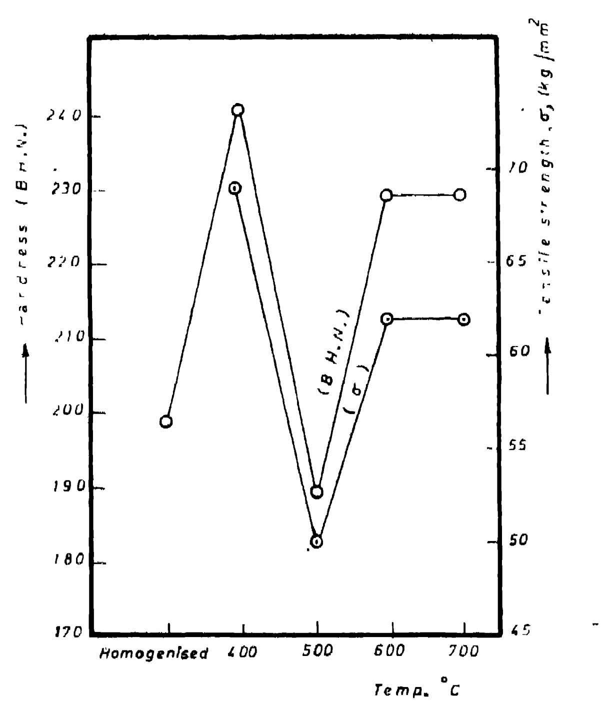

Fig. (1) Effect of tempering temperatures on hardness and tensile strength.

It is clear from these figures, that the hardness and tensile strength have maximum values at 400°C, then they decreased at 500°C and increase again above 600°C. The opposite behaviour is found for the impact strength.

These results will be explained in view of microstructure investigation. Micrographs (2-5) show the phases present at 400, 500, 600 and 700°C respectively while micrograph (1) shows the phases which appear in case of the homogenised specimen at 850°C.

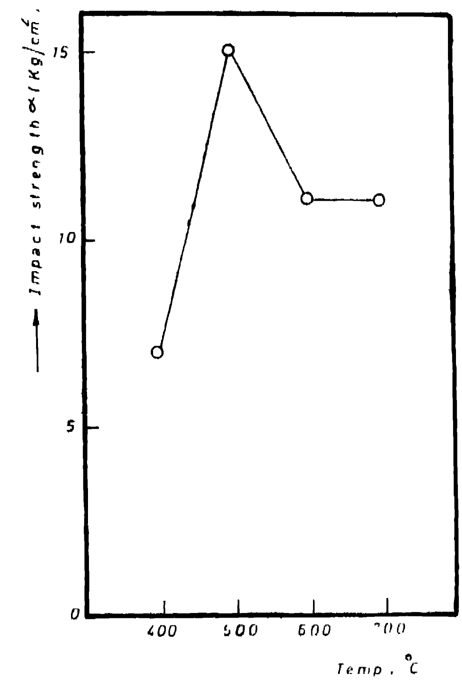

Fig. (2) Effect of tempering temperatures on impact toughness.

Micrograph (1) shows that the phases β and bianite $(\alpha+\beta)$ appeared for the homogenised specimen. While Micrograph (2) shows that the β phase was transformed to α+eutectoid $(\alpha+\gamma)$ hard phase. This explains why the maximum hardness and tensile strength are obtained at 400°C.

The drop in hardness and tensile strength and the increase in ductility at 500°C is due to the formation of β-phase again (micrograph 3).

The increase in hardness again at 600 and 700°C may be due to the formation of either Cu_3Al[22] or $(\alpha+\gamma_2)$ which is predominant. Micrographs (4) and (5) show the appearance of the Cu_3Al with small concentration, which is formed on tempering above 565°C, with martensite rich in Al[22].

Figure 3 shows the comparison of the results of the present work with that of Brozina[22]. It is clear that the highest values obtained by Brozina for hardness and tensile strength were at 400°C which is in good agreement with the present work. Both results show also a drop in hardness and tensile strength at 500°C.

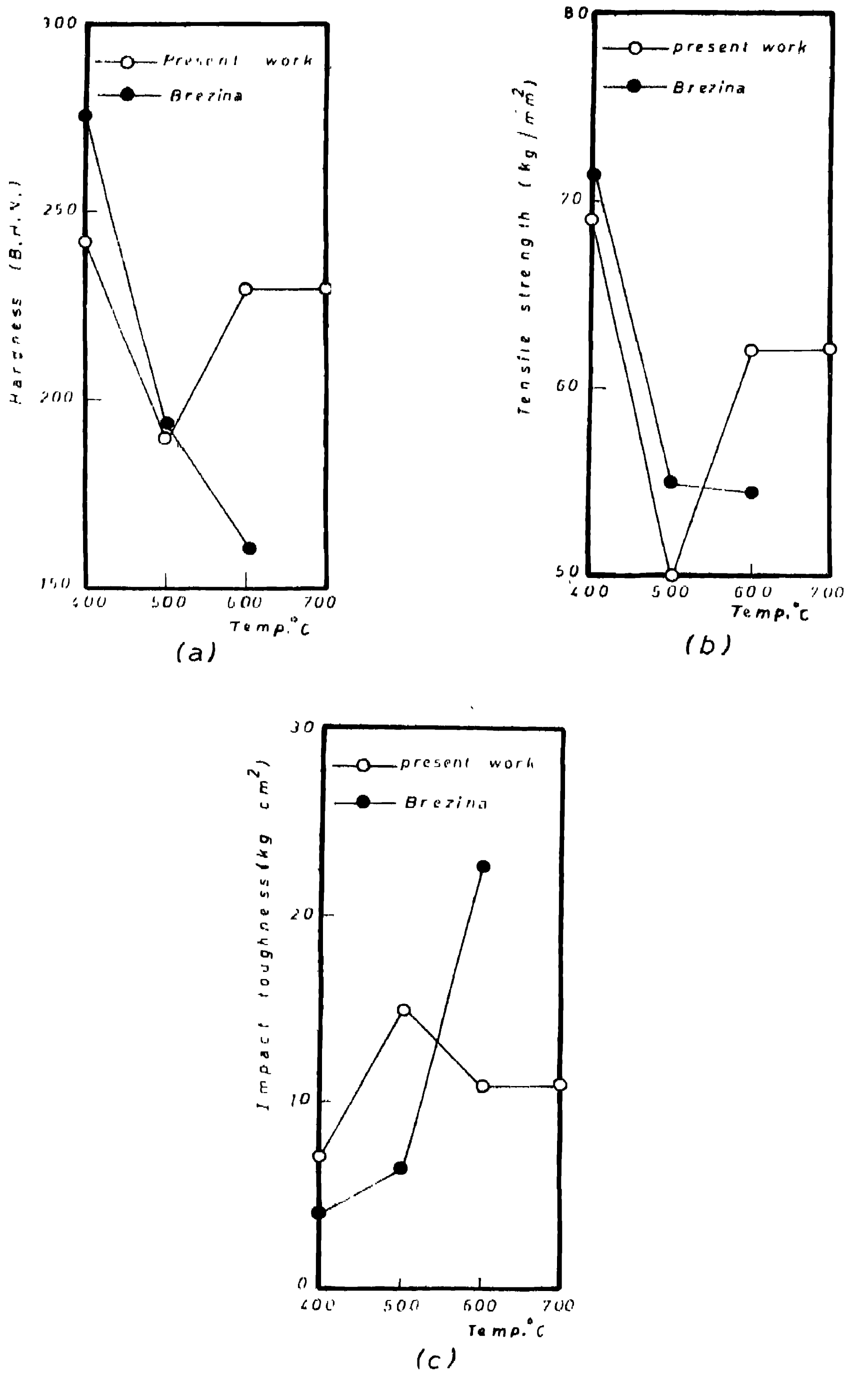

Fig. (5) Effect of tempering temperatures on the mechanical properties. (a) hardness, (b) tensile strength and (c) impact toughness.

The present work shows that the mechanical properties were improved again at 600 and 700°C while Brezina results gave a continuous drop at 600°C. Unfortunately he did not record his results at 700°C, although he mentioned that there is an increase in hardness above 600°C in case of the binary alloy. This confirms the results of the present work.

The difference between both results may be due to the difference in Al percentage in both compositions. The phase diagram[23] of Cu—Al alloy shows that by heating at 600°C for 10.5% Al (the ratio of Brezina) the β phase transformed to the $\alpha+\beta$ phase which decomposes to $\alpha+\alpha$ phase but for 11.6% Al (the ratio of the present work) the β phase decomposes to the hard brittle phase $(\alpha+\gamma_2)$. Therefore, the results of the present work at 600°C are more reasonable than those of Brezina's.

The phases appeared from the microstructural examination of the present work compared with that of Brezina are given in Table 2.

Conclusion

The $(\alpha+\gamma_1)$ hard eutectoid phase is predomenant at 400°C more than at any other tempering temperature. This explains the maximum hardness and brittlness of the alloy at this temperature.

There was a return of the β soft phase at 500°C which caused a decrease in hardness again.

At 600°C, $(\alpha+\gamma_2)$ phases became predomenant but not as at 400°C, while Cu_3Al appeared at 700°C. This explains the increase in hardness again at these temperatures.

Table 2. The phases appeared in the present work and that of Brezina[22]

Tempering temperature (°C)	Phases of the present work (Cu -11.6% Al)	Phases of Brezina alloy (Cu--Al 10.5%)
Homogenised at 850°C	$\alpha+\beta$ (bianite) micrograph (1)	——
400	α' +martensite+$(\alpha'+\gamma_2)$, hard γ_2 is predomenant (micrograph 2 .	α +eutectoid $(\alpha+\gamma_2$
500	$\alpha+\beta$ +eutectoid $(\alpha+\gamma_2)$ β is returned. Eutectoid is not predomenant (micrograph 3)	$\alpha+\beta$ +fine bianite
600	Martensite with high Al content, and some eutectoid $\alpha+\gamma_2$ with less γ_2 than at 400°C (micrograph 4	$\alpha+\alpha'$
700	α +eutectoid $(\alpha+\gamma_2)$ + martensite less eutectoid is fine (micrograph 5)	

REFERENCES

[1] Dominique, A 1969 *Centre Tech. Ind. Fondine*, **281**, 355.
[2] Achirimbeton, Z. & A. Melikhov, V. D. 1969 *Tr. Inst. Yad. Fiz., Akad. Nauk Kaz. (USSR)*, **10**, 91.
[3] Duvall, P. & Hyman, P. 1969 *C.R. Akad. Sci., Ser*, **269**, 408,
[4] Brezina, P. 1970 *Giessereiforschung*, **22**(2), 81.
[5] Milichenko, S. L. & Bykovskii, S. L. 1970 *Svar Proizvod*, **9**, 28.
[6] Mack, D. J. 1948 *Trans. AIME*, **175**, 240.
[7] Haynes, R. 1954 *J. Inst. metals*, **82**, 493 and **83**, 105, (1955), and **83**, 357, (1955).
[8] West D. R. F. & Thomas D. L. 1956-57 *J. Inst. Metals*, **85**, 97.
[9] Thomas D. L. 1966 *Ibid*, **94** (7), 250.
[10] Garwood R. D. 1965 *Special Report* **93**, I.S.I. (London), 90.
[11] Jellison J. & Klier E. P. 1965 *Tran Met. Soc. ALME*, **96**, 1694.
[12] Moon J. R. & Garwood R. D. 1968 *J. Inst. metals*, **87**, 17.
[13] Cope R. G. 1958-59 *Ibid*, **8**, 330.
[14] Jorath R. P. & Mack D. J. 1960-61 *Ibid*, (*Discussion*), **89**(6) 221.
[15] Mallik A. K. 1961 *Trans. IIM*, **14**, 163.
[16] Gowrisankar S. & Mallik A. K. 1962 *Ibid*, **15**, 205.
[17] Jewet R. P. & Mack D. J. 1963-64 *J. Inst. metals*, **92**, 59.
[18] Regidor J. J., Cristina M. C. & Sistiaga J. M. 1974 *Rev. Metal (Madrid)* **10**(3), 165.
[19] Sato H., Toth R. S. & Honjo G. 1967 *Acta Met.* **15**(8), 1381.
[20] Tas H., Delaey L & Dercuyttore A. 1971 *Scr. Met. (Eng.)*! **5**(12), 1117.
[21] Sasmal B. & Das P. P. 1970 *Trans. Indian Inst. Metals.*, **23**(4), 82.
[22] Brezina P. 1972 *Sulzer. Tech. Rev.* (*Res. No*), **29**.
[23] Avener S. H. 1972 Introduction to physical metallurgy.